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New visualizations highlight new information on the contrasting Arctic and Antarctic sea-ice trends since the late 1970s

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ABSTRACT

Month-by-month ranking of 37 years (1979–2015) of satellite-derived sea-ice extents in the Arctic and Antarctic reveals interesting new details in the overall trends toward decreasing sea-ice coverage in the Arctic and increasing sea-ice coverage in the Antarctic. The Arctic decreases are so definitive that there has not been a monthly record high in Arctic sea-ice extents in any month since 1986, a time period during which there have been 75 monthly record lows. The Antarctic, with the opposite but weaker trend toward increased ice extents, experienced monthly record lows in 5 months of 1986, then 6 later monthly record lows scattered through the dataset, with the last two occurring in 2006, versus 45 record highs since 1986. However, in the last three years of the 1979–2015 dataset, the downward trends in Arctic sea-ice extents eased up, with no new record lows in any month of 2013 or 2014 and only one record low in 2015, while the upward trends in Antarctic ice extents notably strengthened, with new record high ice extents in 4 months (August–November) of 2013, in 6 months (April–September) of 2014, and in 3 months (January, April, and May) of 2015. Globally, there have been only 3 monthly record highs since 1986 (only one since 1988), whereas there have been 43 record lows, although the last record lows (in the 1979–2015 dataset) occurred in 2012.

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1. Introduction

The Arctic and Antarctic sea-ice covers have received considerable attention in recent years. The Arctic sea ice in particular has been highlighted as a major indicator of the warming climate, as the Arctic ice cover has both retreated (Parkinson, Cavalieri, Gloersen, Zwally, & Comiso, 1999, Walsh & Chapman, 2001, Stroeve et al., 2012, Meier et al., 2014) and thinned (Yu, Maykut, & Rothrock, 2004, Kwok & Rothrock, 2009, Kwok & Untersteiner, 2011, Laxon et al., 2013), in line with the warming Arctic climate and an array of additional Arctic environmental changes (ACIA, 2005, Jeffries, Overland, & Perovich, 2013, Walsh, 2013). The Antarctic sea ice has expanded instead of retreated over the period of the satellite multichannel passive-microwave record, since the late 1970s (Stammerjohn & Smith, 1997, Zwally, Comiso, Parkinson, Cavalieri, & Gloersen, 2002, Parkinson & Cavalieri, 2012, Turner, Hosking, Bracegirdle, Marshall, & Phillips, 2015), and this largely unexpected trend has caused much interest in the scientific community and various attempted explanations (Thompson & Solomon, 2002, Zhang, 2007, Stammerjohn, Martinson, Smith, Yuan, & Rind, 2008, Turner et al., 2009, Sigmond & Fyfe, 2010, Bintanja, van Oldenborgh, Drijfhout, Wouters, & Katsman, 2013, Raphael et al., 2016). Major changes in the sea-ice covers have potential important consequences for the rest of the climate system (Rind, Healy, Parkinson, & Martinson, 1995, Screen, Deser, Simmonds, & Tomas, 2014, Vihma, 2014, Francis & Vavrus, 2015), for ecosystems (Post et al., 2013, Arrigo, 2014, Meier et al., 2014, Tedesco & Vichi, 2014), and for humans (Johnson, 1999, Walsh, 2013, Meier et al., 2014).

The sharp contrast between decreasing sea-ice coverage in the Arctic and increasing sea-ice coverage in the Antarctic has been portrayed most definitively through time series of satellite passive-microwave data. These time series show that both hemispheres experience noticeable interannual variability in sea-ice coverage but that despite the variability there are significant downward trends in Arctic sea-ice coverage for the annual average, every season, and every month (e.g., Cavalieri & Parkinson, 2012) and significant upward trends in Antarctic ice coverage, also for the annual average, every season, and every month (e.g., Parkinson & Cavalieri, 2012). Through 2013, in each month the downward trends in the Arctic were of higher magnitude than the upward trends in the Antarctic, resulting in consistently negative annual, seasonal, and monthly global ice extent trends (Parkinson, 2014). The addition of 2014 and 2015 data has resulted in one month, May, now having a slightly positive global ice-extent trend, although the global trends for the other 11 months, each season, and the annual average all remain negative.

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In this paper we use the satellite passive-microwave data to rank, month-by-month, the sea-ice coverages in the years 1979–2015 and through visualizations and tabulations of those rankings reveal new details about the ice-extent trends and the interhemispheric contrasts.

2. Data and methods

Satellite passive-microwave data are used to determine the areal coverage of sea ice in both polar regions. These data come from the Scanning Multichannel Microwave Radiometer (SMMR) on the Nimbus 7 satellite and a series of Special Sensor Microwave Imager (SSMI) and SSMI Sounder (SSMIS) instruments on satellites of the Defense Meteorological Satellite Program (DMSP). SMMR was launched in October 1978 and provided every-other-day data for most of the period from launch until mid-August 1987. The first SSMI was launched in June 1987 and has been followed by a series of SSMI and SSMIS instruments that have extended the satellite passive-microwave record on a daily basis almost uninterruptedly since mid-1987. Details about the passive-microwave instruments and the intercalibrations between successive instruments can be found in Gloersen et al. (1992) and Cavalieri et al. (1999, 2012). The intercalibration procedure reduced the ice extent differences between the SMMR and SSMI sensors to less than 0.05% during the period of SMMR/SSMI overlap (Cavalieri et al., 1999) and reduced the yearly mean differences between SSMI and SSMIS to less than 0.031% (Cavalieri, Parkinson, DiGirolamo, & Ivanoff, 2012).

The passive-microwave data allow calculation of the estimated percent areal coverage of ice, termed the ice concentration, at each grid element (or pixel), sized at approximately 25 km x 25 km (Gloersen et al., 1992). The ice concentration data are used to calculate ice extent, which is the sum of the areas of all pixels in the region of interest containing at least 15% sea-ice concentration. Ice extents have been determined for the Arctic and the Antarctic for each month since November 1978 and have been widely used in time series analyses of the sea-ice covers (e.g., Parkinson et al., 1999, Zwally et al., 2002, Stroeve et al., 2012). Here we use the data from January 1979 through December 2015, which covers the 37 years of full-year data.

For each month January through December, we rank the 37 years of monthly ice extent data. For instance, for January, the year with the lowest January ice extent is given a rank of 1, the year with the second lowest January ice extent is given a rank of 2, and on up to the year with the highest January ice extent being given a rank of 37. The same procedure is used for the other 11 months as well. The rankings are visualized through color-coding in three-dimensional (3-D) and flattened (2-D) versions and are tabulated with a month-by-month highlighting of each new record low ice extent and each new record high ice extent. The visualizations and tabulations are done for each hemisphere and for the total global ice extents.

3. Results

3.1. Hemispheric results

Fig. 1a presents the ranked data for the Arctic, color-coded month-by-month from deep red for the lowest sea-ice extent to deep blue for the highest sea-ice extent, and Fig. 1b presents the ranked data for the Antarctic. Many contrasts are immediately apparent. Among the most notable:

(1) In the Arctic, the years with high ice extents (blues) are mostly in the early years of the record and the years of low ice extents (reds) are in the later years of the record (Fig. 1a), whereas in the Antarctic, the high ice extents are more frequent in the later years and the low ice extents are more frequent in the early years (Fig. 1b).

(2) The flow of the rankings is far more systematic in the Arctic (from high ice extents in the early years to low ice extents in the later years) than in the Antarctic, where there are many cases far out of place from the overall flow from lower ice extent in the early years to higher ice extent in the later years. In fact, in the Antarctic the first year of the record, 1979, even has more months in the high half of the rankings (January – July) than in the low half of the rankings (August–December) (Fig. 1).

(3) In the final three years of the 1979–2015 dataset, the Antarctic stands out, with every month of 2013 and 2014 and most months of 2015 being at or near record high ice extent (Fig. 1b).

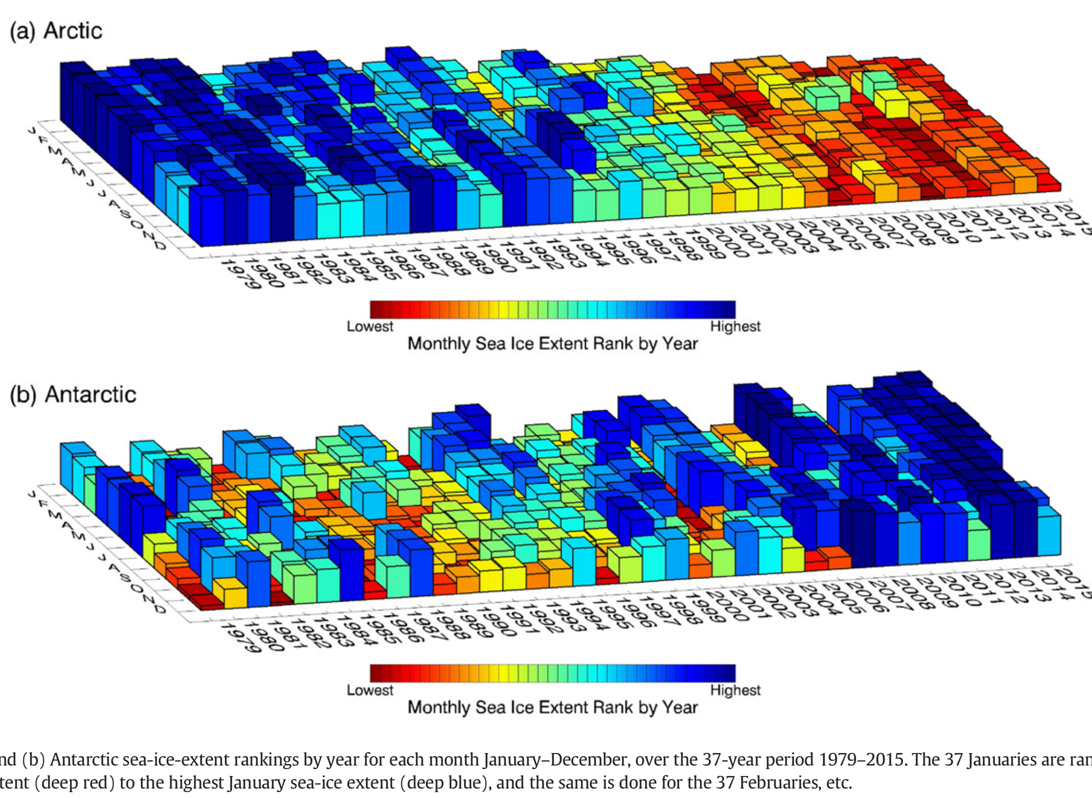

Fig. 1. (a) Arctic and (b) Antarctic sea-ice-extent rankings by year for each month January–December, over the 37-year period 1979–2015. The 37 Januaries are ranked from the lowest January sea-ice extent (deep red) to the highest January sea-ice extent (deep blue), and the same is done for the 37 Februaries, etc.

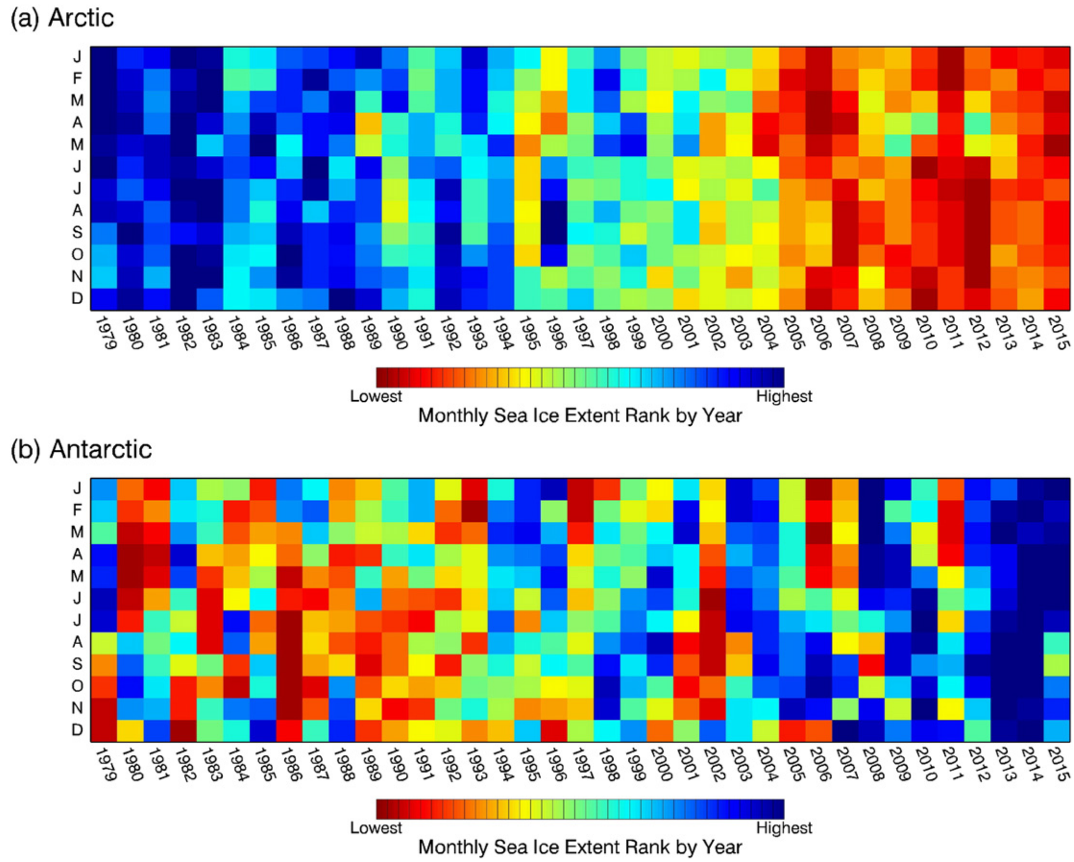

Fig. 2. Flattened view of the information in Fig. 1.

Fig. 2 provides a flat view of the information in Fig. 1. Although less dramatic visually, the flat version cleanly reveals all 444 months, including the few that in Fig. 1 are hidden because of adjacent high ranks obscuring the view, a problem that is particularly prominent in the Arctic in 1995, with several of its low ranks being hidden by the much higher ranks of 1994 (Fig. 1a). The flattened version (Fig. 2), with its complete view of all 444 months, fully confirms each of the three numbered assertions made based on the 3-D version (Fig. 1).

Tables 1 and 2 list the numerical rankings for the Arctic and Antarctic, respectively, and are enhanced by highlighting, for each month, each new record low (for that month) in red and each new record high (again, for that month) in blue. (New record highs or lows have little meaning when the record is only a few years long, but for consistency the highlighting is done through the entire table in each case.)

Stunningly, in the Arctic, the last time *any* month registered a new record high was back in 1986, when a new record October high was reached (Table 1). There have been many record lows (75) since that time, in line with the dominant downward trend in Arctic ice extents. Years since 1986 that stand out with at least four months experiencing record lows are 1990, 1991, 1995, 1996, 2004–2007, and 2012, and years that stand out as having no record lows in any month are 1987, 1992–1994, 1997, 2008–2009, and 2013–2014. In fact, in the final three years of the dataset, the only record low was in May 2015. The last record lows for January and February were in 2011, for March and April were in 2006, for June and December were in 2010, and for July–November were in 2012 (Table 1). (As this article goes to press, it is clear that the year 2016 will have several new record lows, ending the relative drought of new records in 2013-2015.)

In the Antarctic, with its trend toward overall increasing sea-ice extents, there have been six scattered record lows since 1986, the last two coming with record January and March lows in 2006 (Table 2). Record highs since 1986 number 45, several times the number of record

Table 1
Arctic sea-ice-extent rankings by year for each month January–December, over the 37 years 1979–2015. Rankings go from 1 for the year with the least sea-ice extent in the particular month to 37 for the year with the greatest sea-ice extent for the month. Red indicates a new record low for the month, and blue indicates a new record high for the month. Years are indicated at the top, with 1979–1999 written as 79–99 and 2000–2015 written as 00–15.

	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
J	37	30	32	36	35	21	23	28	29	31	34	27	19	24	33	25	22	13	20	26	18	15	14	16	17	12	07	02	09	10	11	06	01	08	04	05	03
F	36	33	27	34	37	19	20	30	35	28	26	29	18	25	31	24	17	13	23	32	21	15	16	22	14	11	03	02	08	12	10	05	01	07	09	04	06
M	37	34	26	35	36	24	29	30	27	33	20	32	19	25	31	21	15	10	23	28	16	13	22	17	18	08	05	01	04	14	09	11	03	12	07	06	02
A	36	35	27	37	33	26	34	28	31	32	11	20	25	21	30	22	13	08	17	24	29	16	23	10	14	04	06	01	02	12	15	18	05	19	09	07	03
M	35	33	34	36	24	28	37	22	31	27	15	21	25	20	23	30	09	16	18	29	32	17	26	10	13	03	08	02	06	11	19	07	04	14	12	05	01
J	37	30	34	35	33	29	31	24	36	23	32	17	27	28	22	25	12	26	20	19	21	18	14	15	16	13	07	05	09	08	10	01	03	02	11	06	04
J	33	28	32	36	37	27	24	30	35	25	29	15	23	34	20	26	12	31	17	18	21	22	13	16	14	19	10	08	03	11	09	04	02	01	06	05	07
A	34	33	28	35	37	27	21	32	24	30	29	14	22	31	20	26	13	36	19	25	18	17	23	12	16	15	10	11	02	06	09	05	03	01	07	08	04
S	27	37	29	31	33	25	24	34	30	32	26	17	20	35	19	28	14	36	22	21	15	18	23	11	16	13	10	12	02	05	09	06	03	01	07	08	04
O	25	33	28	36	35	23	22	37	30	31	27	20	21	34	26	29	12	32	17	19	24	18	16	15	13	14	09	11	02	08	04	06	03	01	10	07	05
N	24	34	25	37	36	22	26	35	30	32	28	27	23	33	31	29	20	16	19	17	21	12	18	14	10	15	11	03	04	13	05	02	06	01	08	09	07
D	32	35	31	37	28	22	23	26	27	36	33	25	21	34	30	29	20	19	24	18	16	17	12	14	15	13	09	02	05	11	08	01	06	03	07	10	04

Table 2
Same as Table 1 except for the Antarctic sea-ice-extent rankings.

	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
J	26	08	04	24	16	17	05	27	22	09	11	19	25	14	03	21	30	34	02	06	18	13	23	12	33	29	15	01	10	36	32	20	07	31	28	35	37
F	24	06	09	23	21	05	07	26	28	10	16	20	25	08	01	27	30	17	02	18	14	12	32	13	33	31	15	04	11	37	19	22	03	29	35	36	34
M	19	02	04	26	20	07	10	09	24	17	15	16	12	06	08	30	32	25	05	23	18	22	33	11	28	29	21	01	13	37	27	14	03	31	36	34	35
A	31	01	02	33	11	10	13	08	17	05	06	20	23	16	14	26	27	29	12	18	19	24	22	07	25	28	21	03	09	35	34	15	04	30	32	36	37
M	30	01	03	29	06	11	16	02	09	07	20	10	18	12	14	23	24	31	15	21	17	33	22	05	28	26	19	04	08	35	34	27	13	25	32	36	37
J	34	02	10	20	03	13	22	05	04	09	25	08	07	06	12	24	15	28	11	17	26	29	21	01	31	27	16	19	14	32	30	35	18	23	33	37	36
J	33	05	20	15	03	31	08	01	11	10	07	06	04	16	14	28	09	24	17	19	27	22	13	02	32	30	25	23	18	21	26	36	12	29	35	37	34
A	15	24	18	22	03	28	10	01	12	07	05	08	16	17	06	25	21	19	14	26	29	34	04	02	09	30	27	32	13	11	33	35	23	31	36	37	20
S	09	28	20	14	18	06	24	01	10	12	03	08	13	05	17	21	15	22	19	31	23	30	07	02	11	32	27	34	29	04	33	26	25	35	36	37	16
O	06	31	23	05	09	02	21	01	03	26	07	12	10	11	18	17	16	13	14	34	25	19	04	08	20	28	29	35	30	15	24	33	22	32	37	36	27
N	02	26	25	05	20	27	28	01	07	29	12	04	06	18	21	16	09	10	11	33	19	14	08	03	23	22	34	31	17	32	15	36	13	24	37	35	30
D	02	12	29	01	18	21	33	04	20	30	06	10	13	14	09	11	24	03	16	22	26	08	17	28	23	15	05	07	37	34	27	32	31	19	35	36	25

lows for the Antarctic but well under the 75 record lows for the Arctic. However, in the Antarctic case, the final three years of the dataset are dominated by record and near-record values, with record August, September, October, and November highs in 2013, record April, May, June, July, August, and September record highs in 2014, and record January, April, and May record highs in 2015. In fact, in the 36 months of 2013–2015, nine had the highest values (for the respective month) of the 37-year dataset, nine had the second highest values, and six had the third highest values, for a total of 24 of the last 36 months having ranks in the top three for the 37 years. Most extreme was 2014, as for that year every month had one of the top four ice extents for that month through the 1979–2015 dataset (Table 2).

3.2. Global results

The global results corresponding to the hemispheric results of Figs. 1 and 2 and Tables 1 and 2 are presented in Fig. 3 and Table 3. As expected with global results combining ice extents from one hemisphere with a strong downward trend and the other hemisphere with a weaker upward trend, the global results are more mixed than those for either hemisphere separately (Fig. 3 versus Figs. 1 and 2). Still, the downward trend in the global results is clear from Fig. 3, with blues (high ice extents) more dominant in the early years of the dataset and reds (low ice extents) more dominant in the last ten years. The prominent valley of low global ice extents in January–June of 2005–2007 (Fig. 3a)

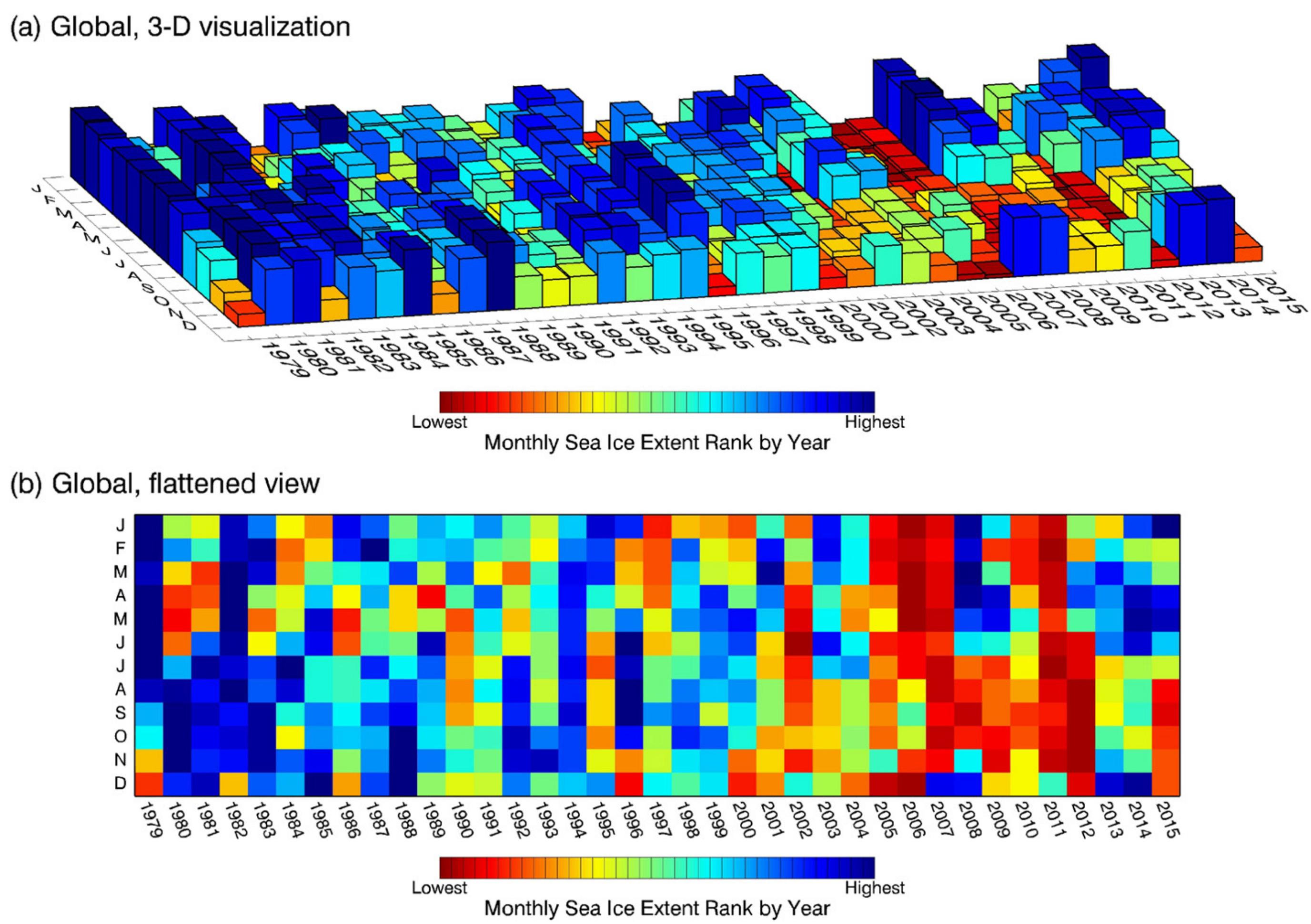

Fig. 3. (a) Global sea-ice-extent rankings by year for each month January–December, over the 37-year period 1979–2015, color-coded from deep red for the lowest sea-ice extent to deep blue for the highest sea-ice extent. (b) Flattened view of Fig. 3a.

Table 3
Same as Table 1 except for the global sea-ice-extent rankings.

	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
J	37	16	14	34	27	13	09	32	28	18	25	22	26	19	15	24	33	30	05	11	10	07	20	08	31	21	04	01	03	35	23	06	02	17	12	29	36
F	36	26	20	34	35	08	12	30	37	21	24	25	19	18	13	27	29	09	07	28	14	11	31	17	32	22	03	02	04	33	06	05	01	10	23	16	15
M	34	12	06	36	33	09	18	21	23	29	16	28	13	08	20	32	30	11	07	24	15	14	35	10	27	22	04	01	03	37	19	05	02	26	31	25	17
A	36	06	07	37	17	14	24	13	25	12	04	19	28	16	22	31	21	15	08	23	30	18	27	05	20	10	09	01	03	35	33	11	02	29	26	34	32
M	36	04	10	37	08	15	33	05	18	12	16	07	23	11	20	30	17	27	14	26	28	31	24	03	22	09	13	01	02	29	32	21	06	19	25	35	34
J	37	08	28	35	13	25	32	07	19	18	34	09	20	14	17	30	10	36	11	16	26	29	12	01	31	22	05	04	06	23	21	15	02	03	27	33	24
J	37	25	35	33	29	36	21	20	30	22	28	10	14	31	17	32	07	34	18	19	27	23	11	05	24	26	09	04	02	08	06	13	01	03	12	16	15
A	34	35	31	37	28	33	21	20	23	29	25	09	22	32	15	30	12	36	18	27	24	26	17	06	11	16	07	13	02	05	08	10	03	01	14	19	04
S	25	37	34	31	35	21	27	22	29	32	24	10	14	30	18	33	12	36	26	28	15	23	17	07	11	16	09	19	04	02	08	06	05	01	13	20	03
O	22	37	32	33	35	13	26	24	25	36	23	18	20	34	27	29	09	31	16	30	28	21	10	11	12	17	08	15	02	05	04	07	03	01	19	14	06
N	11	37	30	31	35	28	32	17	26	36	27	21	18	33	34	29	14	09	15	23	24	08	12	05	10	16	20	06	04	22	03	13	02	01	25	19	07
D	06	30	34	11	28	25	36	10	29	37	17	14	15	27	18	24	26	04	22	19	23	05	09	21	16	08	02	01	32	31	12	13	20	03	33	35	07

reflects unusually low values in the Arctic (Figs. 1a and 2a) combined with predominantly lower than average values in the Antarctic (Figs. 1b and 2b); and the higher values in the last three years of the global record (Fig. 3) reflect the unusually high Antarctic values in those three years (Figs. 1b and 2b).

Globally, there have been only three new monthly record highs since 1986 and only one of those occurred after 1988, that one coming in March 2008. In contrast, there have been 43 new record lows over the same period (since 1986 or 1988, as there were no record lows in 1987 or 1988) (Table 3), clearly reflective of the overall decreases in global ice coverage (Fig. 3). There were four new global record lows in 2012, in four of the five months with record lows in 2012 in the Arctic, and none since then (through the 1979–2015 dataset) (Table 3). The final year of the dataset even has three months that had the second, fourth, and sixth highest ice extents (for the respective month) of the 37-year record (Table 3), reflecting in each case the 2015 record high Antarctic ice extents for the respective months (Table 2).

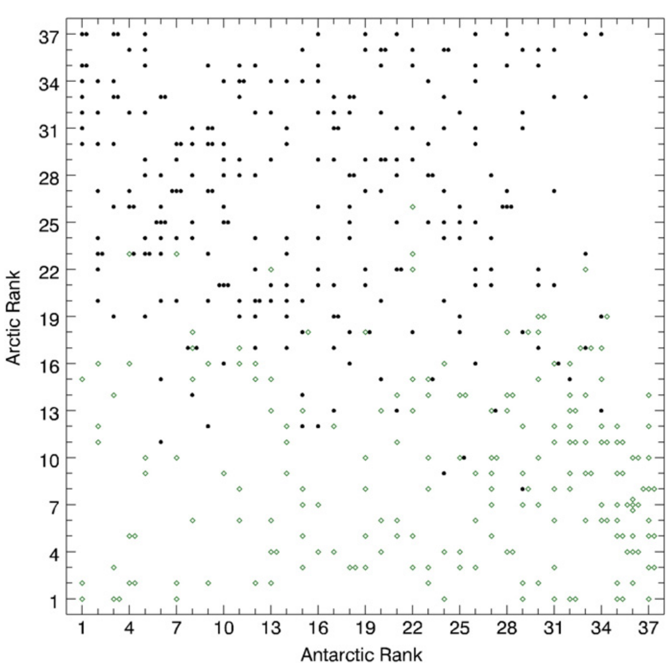

Fig. 4. Scatterplot of the Arctic and Antarctic sea-ice-extent monthly rankings from Tables 1 and 2. Each of the 444 points on the plot represents one month in the 37-year record. The early years (1979–1999) of the record are represented by black dots and the later years (2000–2015) by green diamonds. In cases where more than one dot or diamond belongs at the same location, the second is placed immediately to the right of the first, the third immediately to the left, the fourth immediately below, and the fifth immediately above; one case has five diamonds but no other case has more than three dots and/or diamonds.

3.3. Scatterplot of the Arctic and Antarctic results

The strong negative trend in Arctic sea-ice extents and lesser positive trend in Antarctic sea-ice extents suggests a likely anti-correlation in the two sets of rankings. The calculated correlation coefficient is indeed negative, although with low magnitude. Fig. 4 presents a scatterplot of the two sets of rankings, each point in the plot representing one month of the 444 months in the 37-year record. It is clear from the very large scatter in the plot that the correlation between the rankings is not high (correlation coefficient $= -0.35$). In fact, the lower left point in Fig. 4 shows that one month, identified from Tables 1 and 2 as March 2006, has rank 1 for both the Arctic and the Antarctic, indicating that March 2006 had the lowest March ice extent of the 37 years in both hemispheres. More in line with the opposite trends in the two hemispheres, one month, identified from Tables 1 and 2 as May 2015, had rank 1 for the Arctic and rank 37 for the Antarctic, and two months, October 1986 and December 1982 (Tables 1 and 2), had rank 1 for the Antarctic and rank 37 for the Arctic (Fig. 4).

Color coding the scatterplot to distinguish the early years (1979–1999) from the later years (2000–2015) further confirms the very strong downward trend in the Arctic ice extents, with none of the Arctic's eleven highest ranks in any month being in the later years (2000–2015) and none of the Arctic's seven lowest ranks in any month being in the early years (1979–1999) (Fig. 4). The distinction between the early and later years is nowhere near as prominent for the Antarctic, where the later years span the full distance from rank 1 to rank 37, and the early years span from rank 1 to rank 34 (Fig. 4).

4. Discussion

Over the course of the satellite record since 1979, September has always been the month of minimum monthly-average sea-ice extent in the Arctic (Parkinson, 2014). Hence a September record low in the Arctic is also an overall record low (on a monthly average basis) for the Arctic. (Considering daily averages rather than monthly averages, once in the 37-year record the minimum sea-ice cover occurred in late August rather than in September, although September still had the lowest monthly average.) In view of the decreasing Arctic sea-ice coverage, the importance of ice to the polar climate and ecosystems, and the strong possibility of an ice-free late-summer Arctic at some point within the next several decades, much attention has been given both in the press and by sea-ice scientists to record low Arctic sea-ice extents when they occur (e.g., Comiso, Parkinson, Gersten, & Stock, 2008, Lindsay, Zhang, Schweiger, Steele, & Stern, 2009, Simmonds & Rudeva, 2012, Parkinson & Comiso, 2013, Zhang, Lindsay, Schweiger, & Steele, 2013). In fact, the interest in overall record low Arctic ice extents is so great that there are even internet contests for predicting how low the Arctic ice extent will get for the year and whether it will establish a new record, for example at www.arcus.org/sipn/sea-ice-outlook, where the informal contest is part of a larger sea-ice prediction effort

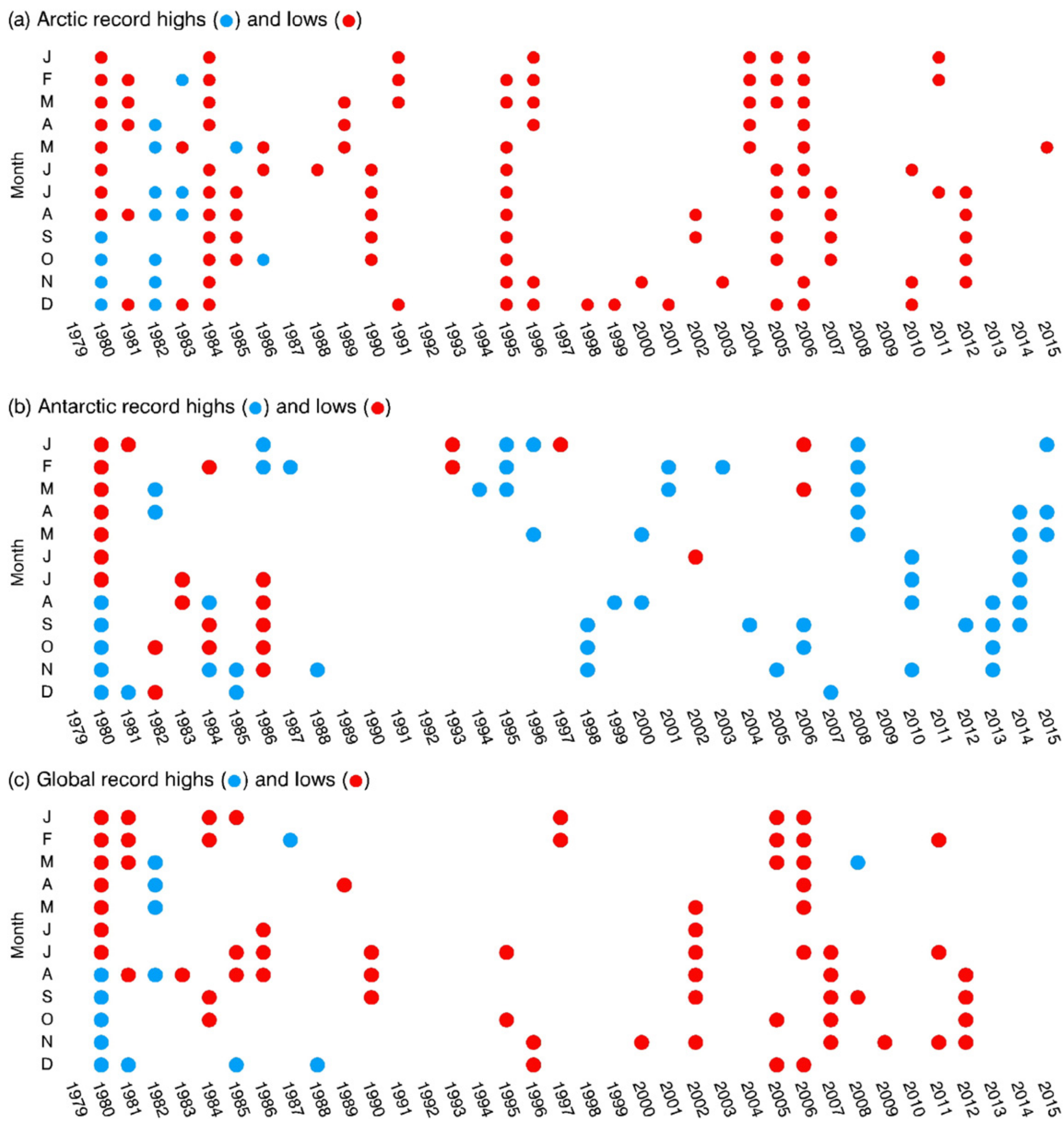

Fig. 5. Summary, from Tables 1–3, of the record high sea-ice extents (blue dots) for each month January–December and the record low sea-ice extents (red dots) for each month, for (a) the Arctic, (b) the Antarctic, and (c) the Earth as a whole.

of the Sea Ice Prediction Network (Stroeve, Hamilton, Bitz, & Blanchard-Wrigglesworth, 2014).

As a result of the wide interest, it is well known in the sea-ice research community that the last two overall record lows in the Arctic (through 2015) were in September 2007 and September 2012. Table 1 confirms those facts for the September record lows but does so much more, systematically providing the rankings for each month throughout the 37 years 1979–2015 and identifying each new record low and each new record high. Similarly, Tables 2 and 3 provide the corresponding information for the Antarctic and global sea-ice extents respectively. Fig. 5 summarizes the record highs and lows, both hemispherically and globally.

The year 2007 not only set a new overall record low for Arctic sea-ice extents (for the period of the satellite observations), equating to a September record low, but also set records (at the time) for the lowest July, August, and October ice extents. The record for each of these months was surpassed in 2012, which through the end of 2015 still holds the record of lowest ice coverage in each of the months from July through November (Table 1 and Fig. 5a). Figs. 1a and 2a depict visually the definitive downward trend in Arctic sea-ice extents in all months of the year, plus the fact of some rebounding from the 2012 record lows in the following year.

Although the Antarctic trend toward increasing ice extents is overall much less systematic than the Arctic trend toward decreasing ice extents (Figs. 1b and 2b versus Figs. 1a and 2a), the last three years of the record are more striking for the Antarctic than for the Arctic. The Antarctic ice extents for every month of 2013 and 2014 experienced among the highest values of the 37-year dataset for the respective month, four months registering new record highs in 2013 and six months registering new record highs in 2014 (Table 2), versus no new record lows in the Arctic in either year. In 2015, the Arctic had one new record low, in May, while the Antarctic had three new record highs, in January, April, and May (Tables 1 and 2 and Figs. 5a and 5b). Interannual variability has always been (from all the data we have so far) a reality of the ice covers of both polar regions.

Reflecting the very different trends in the two hemispheres, the global results show a more mixed pattern, with an overall downward trend (Fig. 3) that is much less definitive than the downward trend in the Arctic (Figs. 1a and 2a). Still, the global results show only three new record highs but 43 new record lows since 1986, with the last record high coming in 2008 (for March) and the last record lows coming in 2012 (for August–November) (Table 3 and Fig. 5c).

We compared the patterns of Arctic and Antarctic sea-ice-extent rankings (Tables 1 and 2 and Figs. 5a and b) with the Oceanic Niño Index (ONI) used by the National Oceanic and Atmospheric Administration (downloaded from http://ggweather.com/enso/oni.htm), with the North Pacific Index by Kevin Trenberth and James Hurrell (downloaded from https://climatedataguide.ucar.edu/climate-data/north-pacific-np-index-trenberth-and-hurrell-monthly-and-winter), and with the Hurrell North Atlantic Oscillation (NAO) Index (downloaded from https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based). None of these yielded clear correlations. Given the interconnectedness of the global climate system, eventually there should be solid correlations established between changes in sea-ice coverage and changes in other major components of the climate system, but so far these remain elusive.

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